University of Technology Sydney

Assisting Product Designers with Balancing Strength and Surface Texture of Handheld Products Made from 3D Printed Polymers

by

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Certificate of original authorship

I, Stefan Lie, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the School of Design, Faculty of Design Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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The world of organized artifice is transforming in ways that are poorly understood and little explored. There are two reasons why this is happening. First, new forms of design and manufacture are appearing that lack historical precedent, and are bound to create substantial novelty. Second, the production methods currently used are not sustainable. They are large in scale, have long histories, and have been extensively researched and developed, but they can't go on in their present form. The status quo uses archaic forms of energy and materials which are finite and toxic. They wreck the climate, poison the populace and foment resource wars.
They have no future.

— **Bruce Sterling in Shaping Things (2005, p. 5)**

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Glossary of terms and abbreviations

3D	Three dimensional.
3D printing	3 Dimensional printing.
ABS	Acrylonitrile Butadiene Styrene, a synthetic thermoplastic polymer used for AM in FDM machines.
Algorithm	A process or set of rules for followed in calculations or other problem-solving operations.
AM	Additive Manufacturing.
Anisotropic	Materials that have different physical properties when measured in different directions.
ASTM	American Society for Testing and Materials
Build orientation	The build orientation is the way parts are placed within the build volume.
Build volume	The specific x, y and z size of the 3D volume an AM machine is capable of building within, where x is width, y is depth and z is height, typically represented in mm. Parts to be built must fit within the build volume.
CAD	Computer Aided Design.
CNC	Computer Numerically Controlled.
DDM	Direct Digital Manufacturing.
DFM	Design For Manufacturing.
DFAM	Design For Additive Manufacturing.
DIN	Is German for Deutsches Institut für Normung (english: German Institute for Standardisation).
DIN EN ISO	The prefix to a test method, e.g. DIN EN ISO 180, that adheres to all three standards.
EN	Is German for Europa Norm (English: European Standard). Member states are required to adhere to EN standards.
End-use product	A product that has been manufactured for actual use, so must be usable, repeatedly if necessary, in the way that it is intended.
FDM	Fused Deposition Modelling.
Generic algorithm	A method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions (mathworks.com).
Handheld product	A portable product that can be used while it is being held and carried by one or both hands, ranging from static products such as bottle openers to hair dryers and complex electronic devices such as digital cameras.
HCI	Human Computer Interaction.

HF	Horizontal Flat. In the context of this research HF stands for a test specimen or part built in the XYZ orientation.
HoE	Horizontal on Edge. In the context of this research HoE stands for a test specimen or part built in the XZY orientation.
HRI	Human Robot Interaction.
I 45	Inclined at 45 degrees. In the context of this research I 45 stands for a test specimen or part built in the XZY at a 45 degree incline along X orientation.
ID	Industrial Design.
ISO	International Standards Organisation.
Isotropic	Materials that have the same physical properties when measured in different directions.
MJ	Material Jetting.
PA	Polyamide, a synthetic thermoplastic polymer used for AM in SLS machines.
Photopolymer	A light activated synthetic thermoset polymer that hardens when exposed to ultraviolet light, used for AM in MJ machines.
Polymer	Commonly referred to as plastic or resin, is a substance which has a molecular structure built up chiefly or completely from a large number of similar units bonded together.
SEM	Scanning Electron Microscope.
SLS	Selective Laser Sintering.
STL file	Standard Triangulation Language, the most widely accepted file format for 3D printing.
Thermoplast	A polymer that is formed by heating it up and hardens while cooling down, can be repeatedly remoulded through reheating.
Thermoset	A polymer that hardens during setting, by means of a chemical reaction that requires heat, cannot be remoulded through reheating or any other means.
TPGDA	Tripropylene Glycol Diacrylate, a synthetic thermoset photopolymer resin used for AM in MJ machines.
UTS	Ultimate Tensile Strength.
V	Vertical. In the context of this research V stands for a test specimen or part built in the ZXY orientation.
Visualisation	The representation of an object, situation, or set of information as a chart or other image.

Abstract

This research provides product designers using 3D printing to manufacture handheld products for end-use with a new approach, which enables them to make knowledge-directed decisions with regard to build orientation in relation to part strength and surface appearance. Because 3D printing machines deposit material in horizontal layers, they become anisotropic, which means they display different physical properties in different directions. To ascertain how much these physical properties differ, test samples were 3D printed in three different polymers and in three different build orientations, which were horizontal at 0 deg, inclined at 45 deg, and vertical at 90 deg.

Product designers also consider how the product will feel and look when it is interacted with, which makes the surface texture a key consideration. The surface of parts made through 3D printing can display characteristics such as stair-stepping; therefore, it is essential to visualise the surface before printing. To address this, six 3D printing software applications were assessed for their ability to visually represent the surface texture of a part before printing. The data resulting from the mechanical property testing was translated into a set of tools that represent the data graphically. The tools enable comparisons to be made between the mechanical properties of the three polymers, namely ABS (Acrylonitrile Butadiene Styrene), TPGDA (Tripropylene Glycol Diacrylate) and PA (Polyamide). The assessment of the six 3D printing software applications showed that Cura provides the most adequate representation of a part's surface.

This research is significant, since to date, no data or tools such as the results presented here on the mechanical properties of the three polymers at a 45 deg incline have been published, nor is there any data that enables the direct comparison of the three polymers in relation to horizontal, inclined at 45 degrees, and vertical build orientations. The ability to visually represent surface texture in relation to build orientation through Cura before printing will assist product designers. Both in combination or individually, the results of this research will provide product designers with a new approach which will help them make knowledge-directed decisions when designing a part to be manufactured through 3D printing in the polymers ABS, TPGDA, or PA.